Functionality of a full-sized marine mammal exclusion device

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CONTENTS

5

Abstract

A full-scale marine mammal exclusion device (MMED) was designed and constructed to standards that make it suitable for use in any New Zealand trawls. The device was shipped to the flume tank in Launceston, Tasmania, where different escape hatch designs were tested using dummy seals. The trials were videotaped and a copy of the tape in VHS format is available.

The device is cheap to produce ($1,500) and the design allows a competent deckhand to insert or remove it in less than 30 minutes. The device lies flat on the deck, takes up little storage space, and can be stored on a net drum. It is easy to use and has no known major deck handling problems.

Three escape hatch designs were tested and all three worked. There was 100% success rate in the exclusion of the dummy from the cod-end. The test results also showed that the device is effective in ejecting dummy seals from the net in about 50% of all trials. Ejection failures had more to do with dummy design and test conditions than problems with the operation of the MMED.

1. Introduction

The incidental capture of Hookers sea lion (*Phocarctos hookeri*), New Zealand fur seal (*Arctocephalus forsterii*), and dolphins is a persistent and serious problem within the New Zealand Exclusive Economic Zone. This report outlines the design and testing of an exclusion device that can be placed inside any commercial trawl operated in New Zealand. The objective of the device is to eject the animal from the trawl before it enters the cod-end where it will inevitably drown.

This report describes the construction and testing of a full-scale marine mammal exclusion device (MMED) in the flume tank at the Australian Maritime College in Launceston, Tasmania. An unexpected consequence of the testing method was the effect of dummy seal design on outcomes. As the design of the dummies was critical, the methods used in construction and testing of the dummies are also given.

2. Design and construction of the device

The principal of operation of the MMED is very simple: it acts like a sieve allowing objects smaller than the distance between the tines, i.e. the fish, to 6 pass through the grid while diverting larger objects, such as sharks, and seals and other marine mammals, towards the top of the net, where there is an escape hatch. The function of the hatch is to create a visual barrier to deter fish escapement without hindering or preventing the escape of large objects such as seals.

The MMED consists of a metal grid fixed inside a netting tube. The grid is inclined at 45° to the water flow, with the top of the grid downstream of the bottom (Figure 1). Floats are attached to the grid inside the netting tube or extension piece so that the overall device is only slightly negatively buoyant. Rope binding around the lower sides and bottom edge protects the device from abrasion. The extension piece containing the grid can be attached or removed from a trawl in a matter of minutes.

2.1 THE GRID

The grid placed inside the extension piece at an angle was constructed from marine grade stainless steel rod of 10 mm and 16 mm diameter. The heavier 16 mm rod was used in the rectangular frame and the smaller, lighter one in the vertical tines.

The mean distance between the vertical tines was set at 20 cm, roughly 75% of the diameter of the smallest common marine mammal caught, i.e. a female or adolescent male fur seal. At this spacing the device will exclude nearly all fur seals, all Hookers sea lions, all common dolphins, and large marine sharks.

FIGURE 1. SIDE VIEW OF THE MARINE MAMMAL EXCLUSION DEVICE IN THE TANK AT THE AUSTRALIAN MARITIME COLLEGE IN LAUNCESTON, TASMANIA.

The cost of constructing the grid was around $300. This may increase slightly with the use of heavier grade rod.

The grid had to be set in the net at an angle to the water flow, and this angle determines its overall dimensions. In this case the angle was 45° measured from the floor of the net to the plane of the grid. The top of the grid is always downstream of the base. This angle is the one commonly used in Europe, but angles less than this can be used.

2.2 CALCULATION OF GRID DIMENSIONS

Let us assume that the stretched mesh size is 120 mm from centre of knot to centre of knot. If the hanging ratio across the mesh is one-third its stretched mesh size we would have a typical centre of knot to centre of knot distance of 40 mm. If there are 120 meshes in the circumference of the cod-end the distance would be:

120 meshes x 40 mm = 480 cm = 4.8 m

Assume that all sides are equal, that is 4.8/4 = 1.2 m = 120 cm. As the grid is set at an angle, its height of the grid must be adjusted so that its end-on profile is square. Let the length of the longest side of the grid be x and the angle the grid forms with the water flow, α. The length of the longest side of the grid can, now be found from:

$x = 1.2/\sin\alpha = 1.2/\sin 45 = 1.69$ m.

Had the angle of attack α been made more acute, say 30°, the length would have been 2.4 m.

The angle of the grid in the current prototype has been set at 45° to the water flow. At this angle, lift and drag are equal. Recent unpublished work in Australia would suggest that the angle can be reduced to around 20° without diminishing its ability to eject objects from the net. Angles greater than 45° could also be considered, as a greater angle would assist ejection from the net, but it might also increase fish escapement.

Some New Zealand trawls have four seams, and the width of each panel should match that of the corresponding panel in the MMED extension piece. The length of the MMED extension piece is determined by the circumference and angle of the grid.

2.3 THE EXTENSION PIECE (NETTING TUBE)

The length of the extension piece in which the grid is placed is determined by the circumference and angle of the grid. At 45° the length of netting required to exactly hold a 1.2 m wide grid is 1.2 m. Allowing for a 1 m overlap of the grid at either end, we have a netting tube 3.2 m long and 4.8 m in circumference. If we assume that the centre of knot to centre of knot length of the mesh under tension is 70% of its stretched mesh length (84 mm), we have a tube 38 meshes long.

Many New Zealand nets have four panels and four seams. To make the tube, three meshes are added to the required dimensions. The three extra meshes from each panel are sewn together to form one siam or selvedge. In most trawls the top and bottom panels are larger than those on the sides. The number of meshes in each panel must be increased by three to allow for the construction of the selvedges or seams.

The cost of constructing the extension piece depends on whether the netting is cut from a new roll or whether offcuts can be used. In general, the netting used to make the extension piece is the same as that used to construct the net, so offcuts should be available. If new netting is used the cost of materials would be around $ 1,000.

3. Design and construction of the escape hatch

Three escape hatch cover designs were considered:
1. Single spacer - a simple design in which the original netting cut away to make the escape exit is stiffened with a single spacing rod along the trailing edge.
2. Wire frame - a net-filled wire frame hatch completely covering the escape exit.
3. Skirting - a series of regularly spaced lengths of twine tied to the leading edge of the escape exit. When water flows, the twine is carried over the escape exit, creating a cover similar in principle to a 'fly screen'.

The principal considerations in hatch design were:
1. The hatch should completely cover the exit - fish are likely to become aware of the grid when just in front of it. At this point, the hatch is forward and above a fish facing the grid in a region of the fish's vision that is particularly acute. If there are any gaps between the edge of the escape exit and the hatch cover, fish inside the net are very likely to be aware of their existence. How they would respond to these gaps is unknown.
2. The hatch should open freely against the flow of water so that the dummy can exit with being hindered.
3. The hatch should not entangle the dummy.

3.1 SINGLE SPACER

The hatch cover was made from the netting cut out to make the escape hatch. The trailing edge was stiffened with a 4 mm metal rod 1.3 m long and with eyes set in each end. The rod sat on top of the trailing edge of the escape hatch entrance. Although this hatch functioned well, it did not completely cover the escape exit but left gaps along each side.

The hatch did not fit well in still water, but (apart from the gaps along the edges) covered the escape exit well when the water was flowing. It opened freely and did not appear to hinder the escape of the dummies. The cost of construction was less than NZ$25.

3.2 WIRE FRAME

A wire frame slightly larger than the escape hatch exit was made from 4 mm steel. The frame had sides angled down and was slightly longer than the escape exit. It was filled with netting of the same type as that of the extension piece.
The leading edge of the escape hatch frame was sewn to the leading edge of the escape hatch. There were no gaps along the edges. The hatch cover fitted well at all water speeds and opened well to allow the dummies to exit at 3.2 knots. The cost of construction was less than $75.

3.3 FLOWING SKIRT

Lengths of twine were attached at regular intervals to a rope, which was attached to the leading edge of the escape exit. At no current, the twine hung down but, at water flow speeds of 1.5 knots and above, it trailed out along the flow of the current and completely covered the escape exit. The efficiency of this method at preventing fish escapement will depend on direct observation of its performance with live fish. In this case 6 mm netting twine was used, but other materials including plastic ribbon could also be used. It is expected that the material should be selected on the basis of its fish-retaining properties. This hatch type operated well. However, the skirting has a very different appearance to the normal netting, and its effectiveness in preventing fish escapement is unknown. The cost of construction depends on the materials used but is mostly labour.

4. Design and construction of the dummy seal

Three wet suit fabricators were contacted, and the dimensions and specifications of the dummy seal were sent to them. The companies were asked how they would construct a dummy to the correct dimensions that was neutrally buoyant and robust enough to withstand the tank tests. The companies providing the two best solutions were asked to proceed.

4.1 DUMMY SEAL SPECIFICATIONS

Each seal must have a zipper up half its length, must be shaped like a teardrop, and have a ring attached at one end. Each dummy was made from 8 mm neoprene with cloth on both sides. All seams were glued and stitched, with the ring attached using heavy-duty webbing sewn and glued to the body. Typical dimensions of an adolescent male and adult female, obtained from Dr Rob Mattlin, were: body length, 1.2 m; and circumference at widest point, 0.8 m (at 1/3 the body length, 0.4 m from the head). When supplied, both seals were of similar dimensions and overall shape.

4.2 SHAPING METHOD FOR DUMMY SEAL

Dummy seal 1 (DS 1) was filled with plastic piping that had been threaded on to a string to prevent shifting. The surface of the seal in air was relatively smooth and seal-like, but in water the presence of the pipes underneath the neoprene was noticeable. Dummy seal 2 (DS 2) was filled with cotton netting to pack the neoprene out into its natural seal shape. The netting gave the dummy shell a good seal shape in and out of the water.

4.3 FLOATATION

The seals were submerged until all the air had been released, and then weights were added until the dummy seal was neutrally buoyant. DS 1 was fitted with a metal ring for attachment of the line.

4.4 BALANCE

The positions of the weights were adjusted along the length of the dummies to ensure that both seals sat parallel to the surface. At the start of the trials the metal ring gave DS 1 a slight tendency to sink head first. At the end of the trials there was a tendency for both dummy seals to sink head first because the weights inside had shifted during the trials.

4.5 APPENDAGES

Neither of the seals was made with appendages. After a number of tests a pair of divers' flippers were attached to the tail end of DS 2. This increased the speed 11 at which the seal travelled towards the grid, and decreased the sticking properties of the dummy, but increased the failure to exit because of entanglement of the flippers. Examination of the videotape revealed that the dummies were getting wedged in the tines by the protruding ridge where the flippers joined the body. The divers' flippers were removed and replaced with flippers made from a sheet of rubber. These were sewn to the body to reduce the level of entanglement caused by the uneven nature of the attachment. However, this remedy was only partially successful.

5. Testing and recording method

The MMED was inserted into a tube to simulate its insertion in a commercial trawl. The forward tube was kept open by attaching a metal hoop to the leading meshes. A metal chain was attached to one side of the hoop and a float to the other. This arrangement ensured that the hoop always adopted the same attitude in the water when submerged. Ropes attached to the hoop were fixed to shackles and then fixed to vertical struts inside the tank. This arrangement allowed the device to be raised and lowered in the water column. When the water flowed, the device streamed out downstream in the same way as it would in a trawl (Figure 2).

FIGURE 2. THE MARINE MAMMAL EXCLUSION DEVICE IN THE TANK AT THE AUSTRALIAN MARITIME COLLEGE IN LAUNCESTON, TASMANIA. A DUMMY SEAL IS SHOWN IN THE MOUTH AT THE ENTRANCE TO THE DEVICE.

12

5.1 DUMMY POSITIONING AND RELEASE

The dummy seals could not be dropped into the mouth of the net from the platform over the MMED and so some means of holding the dummy in, away from of the mouth of the device when the flow was at 3.2 knots, was required.
A pulley was attached to a plastic box, which was then filled with 80 kg of lead weights to prevent it being pushed down the tank by the force of the water flow. A line was attached to the front of the dummy seals and passed through the pulley. Pulling on the line pulled to dummy seal under water towards the pulley in front of the MMED.When the water was flowing, the dummy seal trailed downstream of the pulley in front of the MMED (see Figure 2). Releasing the tension on the line allowed the current to take the dummy backwards into the mouth of the MMED. A limitation of this release method was that the presentation of the dummy to the grid could not be varied, i.e. it was not possible to pass the dummy into the net sideways. Another limitation was that the velocity of the dummy at the point it met the grid was much less than the water speed. The distance between the point of release and the grid was too short for the dummy to reach the same speed as the water. In some tests a line was attached to the front of the seal and used to accelerate it to the water speed.
At full flow rates the line leading to the pulley bowed downstream, creating drag and hindering the free flow of line through the pulley. To alleviate this problem a finer line was used to secure the dummy.

5.2 RECORDING METHOD

A dummy was released just in front of the entrance to the 6 m extension piece attached to the front of the MMED. The observed effects of sticking and flipper entanglement were recorded as present (□) or absent (-). Hatch operation was recorded as normal (□) if the hatch opened to allow the dummy to fully or partially pass through the exit without becoming entangled with the hatch cover. Hatch operation was regarded as abnormal if the dummy was prevented from exiting the net by entanglement or malfunction of the hatch cover. Most of the trials were recorded on videotape, but some were missed because of a technical problem with the remote panning function on the camera. A representative sample of 20 video clips covering successful and unsuccessful trials on all three hatch types have been included on a summary videotape.

13

6. Test results

Initial tests showed that escapement of passive dummy seals was affected by water flow rate. At 1.5 knots, none of the dummies exited the net, but at 3.2 knots, six of the nine tests resulted in escapement. All further tests were carried out at 3.1 knots, which is much slower than typical towing speeds in New Zealand. When the dummy hit the separator grid, the water flow would push it hard against it. Its neoprene skin would not generally slide against the vertical bars and the piping with which DS 1 was stuffed caused ridges in the skin that caught underneath the horizontal bar. Once the dummy struck to the grid, the force of water made the ridges more pronounced and wedged the dummy against the horizontal bracing bar in the grid. Once stuck in this fashion, the dummy did not usually free itself. Because of the poorer performance of dummy seal DS 1, further use of it was stopped and all further testing was carried out using DS 2.

6.1 HATCH A: SINGLE SPACER

This design did not completely cover the escape exit. There were small gaps along each side and at the trailing edge of the hatch cover. In five of the eight trials the dummy left the net (Trials A2, A3, A4, A7, and A8). In Trial A3 the dummy only partially left the net, as it became entangled by the flippers. In Trials A5 and A6 the flippers became entangled with the horizontal bar and the dummy remained in the net (Table 2). The escape hatch operated well and did not entangle the dummy.

TABLE 1. THE NUMBER OF DUMMIES STICKING, TANGLING AND EXITING THE MMED DURING PRELIMINARY DUMMY TRIALS.

	Sticking	Tangle	Exit
DS 1	8	-	1
DS 2	4	3	5

TABLE 2. TRIAL RESULTS FOR DUMMY TYPE DS 1 WITH A SINGLE SPACER HATCH DESIGN (HATCH A). THE OCCURRENCE OF STICKING, FLIPPER ENTANGLEMENT, NORMAL HATCH OPERATION, AND ESCAPES FOR EACH TRIAL IS SHOWN BY □ . WHERE A VIDEO REFERENCE IS AVAILABLE IS ALSO SHOWN.

Trial Sticking Tangle Hatch operation Escape Video

A1 □ - □ - □
A2 - - □ □ □
A3 - □ □ □ □
A4 □ - - □
A5 □ □ □ - □
A6 □ □ □ -
A7 - □ □
A8 - □ □ □

6.2 HATCH B: WIRE FRAME

There were no gaps around the edges, as the hatch was slightly larger than the size of the escape exit. In five of the eight trials the dummy left the net, but in two of these, escape was incomplete as the dummy was held by the flippers (Table 3).
The hatch operated well and did not entangle the dummy.

6.3 HATCH C: FLOWING SKIRT

There were gaps between the strands of the skirt, and the appearance of the skirting was quite different from netting. This hatch design relies more on fish behaviour and less on a physical block than the other two designs. The different visual appearance of the hatch cover is likely to have an effect on the behaviour of the fish, but its effect on fish escapement is unknown.
The hatch cover operated well and presented no obstacle to the passage of the dummy during exit. In Trial C8 the dummy stuck to the bars of the grid. The results of these trials are given in Table 4.

TABLE 3. TRIAL RESULTS FOR DUMMY TYPE DS 1 WITH A WIRE FRAME HATCH DESIGN (HATCH B). THE OCCURRENCE OF STICKING, FLIPPER ENTANGLEMENT, NORMAL HATCH OPERATION, AND ESCAPES FOR EACH TRIAL IS SHOWN BY □ . WHERE A VIDEO REFERENCE IS AVAILABLE IS ALSO SHOWN.

Trial Sticking Tangle Hatch operation Escape Video

B1 □ - □ - □
B2 - □ □ □
B3 - - □ □ □
B4 - - □ □
B5 - □ □ - □
B6 - □ □ - □
B7 - □ □ □
B8 □ - □ □

TABLE 4. TRIAL RESULTS FOR DUMMY TYPE DS 1 WITH A FLOWING SKIRT HATCH DESIGN (HATCH C). THE OCCURRENCE OF STICKING, FLIPPER ENTANGLEMENT, NORMAL HATCH OPERATION, AND ESCAPES FOR EACH TRIAL IS SHOWN BY . WHERE A VIDEO REFERENCE IS AVAILABLE IS ALSO SHOWN.

Trial	Sticking	Tangle	Hatch operation	Escape	Video
C1	-	☐	☐	-	☐
C2	-	-	☐	☐	
C3	-	-	☐	☐	☐
C4	☐	☐	☐	-	☐
C5	-	☐	☐	-	☐
C6	-	☐	☐	-	☐
C7	☐	-	☐	☐	
C8	-	-			

6.4 OVERALL ESCAPEMENT

All hatch designs worked well but the wire frame provided a better cover of the exit. None of the designs hindered the escape of the dummy. Sticking and flipper entanglements are problems associated with work on dummy seals not real animals.

Sticking, when the dummy hit the grid and stayed there, was a problem in all tests. With DS 1 the underlying topography of the pipe filling exacerbated the problem and led to a high rate of failure to exit. The lack of piping and the turgid nature of the netting stuffing improved the ejection rate of DS 2. In some instances it was possible to pull the dummy slightly, and this movement was sufficient for it to be dislodged and ejected from the net by the flow of water (e.g. Trial A8).

Flipper entanglements were common and were largely attributable to the tailfirst attitude of the delivery method. Once the flipper passed between the tines, the dummy was swept to the top of the grid. Sometimes the flippers got caught on the horizontal bracing bar in the grid but more usually on the top edge of the grid itself (Figure 3). If the dummy was caught on the upper edge of the grid, it would invariably exit the net but be held fast by the flippers (see Figure 3).

Some trials were conducted by sending the dummy down the net head first, but generally it did not reach the same terminal speed as those sent down tail first, and this contributed to a higher failure-to-eject rate.

The video clips included on the available tape are given in Table 5. Each clip is labelled on the tape.

FIGURE 3. A DUMMY SEAL CAUGHT BY THE FLIPPERS DURING A TRIAL OF THE EXCLUSION DEVICE IN THE FLUME TANK.

7. Discussion

All the escape hatches tested here worked well, but the single spacer type did not cover the exit as well as the wire frame type. The skirting type of hatch cover can be made from a variety of materials, but the choice of the most

appropriate material will depend on the response of target species rather than physical considerations.
The results of these trials should be viewed with caution, as they are only an approximation to a complex situation. The following points should be considered

:

1. Entanglement with flippers is unlikely to be an issue with real seals. The main cause of entanglement was the catching of the flipper insertion point around the bars. This is unlikely to occur with real seals because their flippers are a continuation of the body.
2. Escapement is expected to improve with animal movement. The dummies tested were completely passive and dead weights. Any movement of the animal will assist its ejection from the net.
3. Neoprene is not a good substitute for oily fur. Fur will slide along the bars better than neoprene.

TABLE 5. TABLE OF SUBJECT AND STARTING AND ENDING TIMES FOR THE
VIDEO CLIPS INCLUDED ON THE AVAILABLE TAPE.

Video clip	Subject	From	To
0	Introduction	0:00	01:15
1	MMED	01:18	03:58
2	Seal outside	04:04	04:53
3	Hatch A	05:00	07:24
4	Hatch B	07:31	08:24
5	Hatch C	08:30	10:06
6	Trial A1	10:13	10:28
7	Trial A2	10:36	10:56
8	Trial A3	11:03	11:38
9	Trial A5	11:45	12:10
10	Trial A6	12:15	12:37
11	Trial A8	12:43	13:18
12	Trial B1	13:28	13:46
13	Trial B3	13:52	14:04
14	Trial B5	14:12	14:22
15	Trial B6	14:30	14:43
16	Trial C1	14:55	15:10
17	Trial C3	15:15	15:28
18	Trial C4	15:35	15:45
19	Trial C5	15:55	16:12
20	Trial C6	16:28	16:35

4. The water flow of 3.2 knots was only about 70% of that in commercial trawls. Increased water flow rate increases the force available to eject a passive object.
5. Pushing water through a fixed net is not the same as pulling a net through still water. There are subtle hydrodynamic differences between the two. Although it might have been possible to increase escapement with the dummy, the causes of the failures were primarily associated with the design and construction material of the dummy. Further work would necessarily have focused on developing a better dummy seal, but this was not the point of the tests. The objective was to see if a passive object the same size and shape as a seal could be expelled from a fishing net using a device that could be easily fitted to a commercial trawl. The answer to this question is clearly yes. The issues that need to be addressed now require work with live fish and concern escapement and fish quality. The MMED would be of little practical use if the escapement unduly affected catch rates or catch value. Further development of the MMED would require tests at sea to examine levels of escapement and the effect of the grid on fish quality. These issues could be examined using escape hatch covers and trouser trawls. Recommendations for further work along these lines are given in the Appendix (Section 10.1).

8. Conclusions

1. A marine mammal exclusion device (MMED) has been designed for use in New Zealand.
2. An MMED can be manufactured at an affordable price.
3. An MMED of this design can be easily fitted and removed from a trawl by a competent deckhand in less that 30 minutes.
4. The MMED design used here lies flat on the deck and, with the use of larger diameter steel, can be stored on a net drum.
5. The MMED design used here is robust and easy to use.
6. The MMED design tested here was 100% effective in excluding dummy seals from the cod-end.
7. The MMED was around 50% successful in ejecting the seal dummies from the net. Almost all failures can be attributed to dummy design not faults in the MMED.

18

9. Acknowledgements

I am indebted to Peter Cover, of the Australian Maritime College in Launceston, for his assistance and his permission to use the surface and underwater footage of fur seals in the introduction on the videotape.

19

10. Appendix

10.1 EFFECT OF THE EXCLUSION DEVICE ON FISH QUALITY AND FISH ESCAPEMENT

A major concern about the use of the device is its effect on product quality. In this context, reduced quality refers to physical damage to the fish caused by direct contact with the vertical tines and frame of the grid. Fish is damaged during normal trawl fishing operations and it is important to distinguish this from that attributable to the MMED.

To do this I propose to conduct an experiment with a trouser trawl, a trawl with two separate cod-ends. Four conditions need to be examined and these can be set up independently in each leg:

1. control - no device,
2. MMED with normal tine spacing,
3. MMED with narrow tine spacing,
4. MMED frame without tines.

These experiments might have to be conducted for three different species, squid, southern blue whiting, and hoki. It is important that commercial operating conditions prevail, so that other factors that may affect fish quality can be as similar as possible to those that would normally operate in the fishing fleet. Fish quantity would be measured as weight and number of fish caught per codend. Physical damage would be scored on a random sample of fish taken from each cod-end. It would be done by external examination of anatomical location. The sample would also be filleted and the number of blood spots counted by candling each fillet. Fish length and catch size might affect the level of damage and would be treated as a co-variates. The number of replicate tows and the number of fish per sample would depend on the level of damage encountered and the required levels of precision and confidence, high levels generally requiring larger sample sizes and a larger number of replicates. The sample sizes and number of replicates would be calculated when an estimate of the expected proportion of damaged fish was known. There would be four treatments, two cod-ends (left and right) and one co-variate (length). Although cod-end should not affect the results, it could be factored into the experimental design with little extra effort. Analysis of the results would depend on the units of the dependent variable; in the case of blood spot counts, a Poisson regression would probably be the most suitable. With the scores for external damage, simple tabling and graphical representation of the results would be complemented with hierarchical log-linear models and correspondence analysis.